COLLISION AVOIDANCE CAPABILITIES OF OLDER DRIVERS AND IMPROVEMENT BY WARNING PRESENTATIONS

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ABSTRACT

The avoidance behavior of drivers over the age of 65 was compared with drivers under the age of 60 years in an emergent traffic situation where an obstacle vehicle drives into a blind intersection in a driving simulator. The drivers generally tended to do their best driving as the required reaction time in the situation decreased. However, the avoidance performances of the older drivers were more restricted than those of younger drivers; e.g., the maximum steering velocity was around 250 deg/s for the older drivers but 450 deg/s for the younger drivers. The older drivers needed a greater time margin, ranging from 1.35 to 2.7 s, than the younger drivers to successfully complete the avoidance. It was suggested that the avoidance abilities of the older drivers could be attributed to their mental and physical traits; their avoidance performances were remarkably improved by presenting advanced auditory warnings 3.0 seconds before their arrival at the intersection.

INTRODUCTION

Older people now represent a large part of the population throughout the world, especially in developed countries. The population of advanced-age people in Japan is progressing rapidly (in only 21 years, from 1985 to 2006, the proportion of the population over age 65 years grew from 10% to 20% of the total Japanese population), and it will reach a high level (the proportion of the population over 65 will become 32% in 2050) with a constant increase in the population over 75 years old.

In pace with these demographic population changes, many older people licensed to drive are behind the wheel in traffic in Japan, and the number of older drivers will continue to increase in this new century. Traffic collisions caused by older drivers are tending to increase, with collisions at relatively low speed and crossing path collisions at intersections as particularly remarkable traffic accidents that involve older drivers (1).

Various psychophysiological functions related to driving behavior gradually deteriorate in accordance with advances in age; e.g., a narrowing of the functional or detectable field of view (2), performance decline in simultaneously carrying out multiple tasks (3), delayed reaction times to the appearance of the brake lights of a vehicle ahead of the driver (4), and a gap-acceptance tendency to gauge only the distance to an oncoming vehicle without considering the relative velocity between one's own and oncoming vehicles (5). Results from these researches illustrate an age-related deterioration of perception, information processing, and motor skills, which increase the risk of encountering dangerous driving situations.

However, the coping capabilities of older drivers to handle critical events once the dangerous driving situation has occurred are not sufficiently clarified. Some laboratory experiments revealed a deterioration of steering tracking performances and a slowdown of the steering angle input of older drivers (6). Driving behavior to avoid apparent and immediately dangerous events is expected to be affected by age-related changes in control performances. However, there are currently few empirical results that explicitly illustrate the emergent avoidance capabilities of older drivers in terms of whether they can avoid collisions and what is causing the results of their avoidance behaviors.

Another important feature of aging is individual differences. The relative changes observed in mental or physical traits can affect the avoidance capabilities of older drivers. An examination of the effects of various psychophysiological traits on older drivers' avoidance behaviors would contribute to improvements in safety measures.

This research is aimed at obtaining usable results to improve the safety performances of older drivers by means of clarifying their avoidance capabilities in a real emergent traffic situation. For the purposes of this research, view-obstructed intersections were installed in the visual database of a driving simulator, and a driving scenario was set to represent crossing path collisions similar to typical collisions involving older drivers. The results of avoiding maneuvers and steering wheel and pedal manipulations were compared across the driver age groups in order to distinguish the characteristics of older drivers. Psychophysiological traits were measured before the driving experiment in a simulated emergent situation to allow for individual differences among the older drivers, and the relationship between the results of their avoidance and visual perception and information-processing abilities were examined. The effectiveness of an advanced collision warning for older drivers was also assessed.

METHOD

Setting the Driving Situation

We used the JARI driving simulator (7), which has a six-axis motion base and presents computer generated visual images to a driver. An emergent traffic situation was provided wherein an obstacle vehicle drives out from a left side road at blind intersections.

We simulated a straight urban area road that connected to intersections. The road was 7.0 m wide, was separated into two lanes by center line marks, and had shoulders 0.5 m wide adjacent to 1.0 m wide pedestrian sidewalks and buildings. This road was constructed with an acceleration section (300 m), an experimental section (1680 m), and a braking section (300 m). Twenty intersections in which perspectives were blocked by roadside buildings were set every 80 m in the experimental section, and *critical intersections* where a red sedan rushed out from a left side road were set at five arbitrary intersections. Since all intersections had equal geometry and the allocations of the critical intersections were randomized, the subject driver could not anticipate at which critical intersections the obstacle vehicle would appear.

The positions where the obstacle vehicles first became visible to the driver were experimentally controlled by means of setting the initial locations of the obstacle vehicles, using the occlusion of the left side road by a roadside building, as shown in Figure 1.

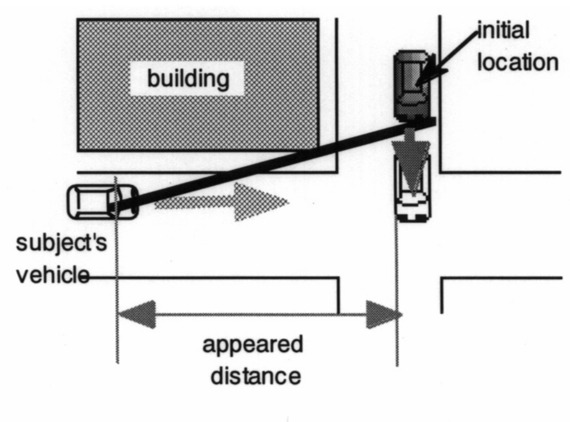

Figure 1 Setting Appearance Distance.

The *appearance distance* was defined as the interval between the position where the obstacle vehicle first became visible and the expected collision position (i.e., center of the intersection). Five levels of appearance distances were provided on the experimental section, located by decreasing the appearance distance according to progression on the road; i.e., the appearance distances were 50, 40, 30, 20, and 15 m in the order of earlier appearance. The obstacle vehicle coming from the left side road stopped at the center of the intersection and blocked the left lane in every appearance distance, so the subject driver had to perform avoidance maneuvers by braking and/or steering control. Figure 2 shows the driver's view immediately before a critical intersection.

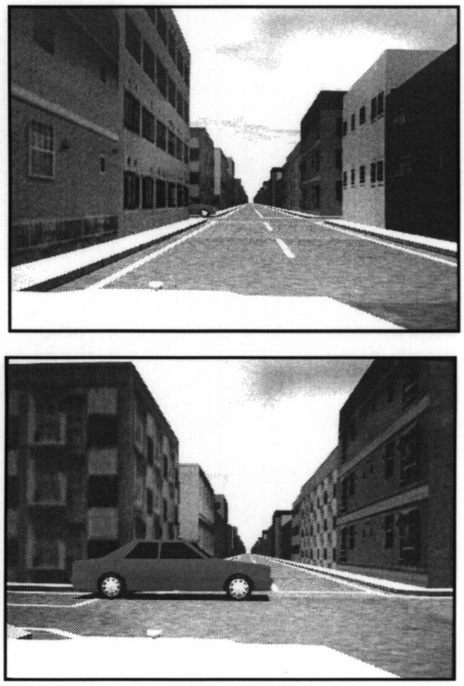

Figure 2 Front View from Driver's Visual Perspective.

Experimental Conditions

Two levels of evasive action factors were provided: *brake plus steering evasion*, which allows the driver to maneuver with both the brake pedal and steering wheel, and *steering evasion*, which allows only a steering wheel maneuvers. Two levels of velocity factors, *40 km/h* and *60 km/h*, were also provided for driving on the experimental section. Each subject driver was required to drive on the simulated road under all four conditions, which combined the evasive actions and velocity factors. Driving behavior in regard to pedal and steering manipulations were measured for every five levels of appearance distances in each of the four conditions.

A steering evasion condition at a velocity of 60 km/h was also provided as a *warning condition* to examine the effect of advanced warning. In this condition, a tonal warning sound was continuously presented when the subject's vehicle was 50 m from the critical intersection. This setting put the timing of the warning at 3.0 seconds before arrival at the critical intersection. The timing of the warning was chosen based on our previous results, which revealed the required visible distance from which most younger drivers could successfully avoid the obstacle (8). The alerting tone was a pure tone of 1 KHz with 70 dB(A) of sound pressure level with an intermittent 0.2-second cycle and 70% duty rate; this specification ensured a higher level of perceived criticality and urgency in the authors’ other research (9, 10). No false alarm or missed warning was set in this experiment.

The simulated vehicle was a sedan 4.7 m long and 1.7 m wide with right-hand drive. The subject drivers were twelve male drivers over the age of 65 years who participated as the *older group* (ages ranged from 68 to 81 years, the mean value was 75.6 years) and twenty male drivers younger than age 60 who participated as the *younger group* (ranging from 26 to 57 years, the mean value was 40.0 years).

Procedure

The driving simulator experiment was preceded by trials to assess the psychophysiological traits of the subject drivers. The following traits were measured in a laboratory situation: visual acuity rate (rate of dynamic acuity to static acuity), field of view (square measure of horizontal and vertical visible angles), multiple task performance (mean value of choice reaction times to three colored lamps), and personality traits (self-ratings indicating stable-positive personality traits measured by a modified Guilford Personality Inventory).

After completing the above analyses, the subject driver was instructed as to the purpose and procedure of the driving simulator experiment and rode in the simulator. Five experimental driving trials were preceded by a practice trial of simulator driving with the brake plus steering evasion condition at a velocity of 40 km/h. The sequence of experimental trials progressed from the brake plus steering evasion conditions to the steering evasion conditions to the warning condition. The velocity conditions were enforced in random order. The time required to complete all the trials to collect psychophysiological traits and the driving experiment was around 90 minutes.

RESULTS

Properties of Avoidance Behaviors

Figure 3 shows an example of the measured avoidance behavior for a subject driver. Two peaks were typically observed for the steering wheel angle as a consequence of the following maneuvers. The driver first started a right steering maneuver aimed at passing the obstacle vehicle, then turned the steering wheel to the left to prevent a deviation from the right side lane, and finally turned rightward again to correct the vehicle posture. The following measures were chosen to analyze the avoidance behavior based on these avoidance maneuvers. For steering maneuvers, we measured the latency from the vehicle rushing out from the side road to the visible start of the steering maneuver, the steering angles at the first and second peaks, and the steering angular velocities from the start of the steering maneuver to the first peak and from the first to second peaks. We analyzed the latency from when the obstacle vehicle became visible to the release of the accelerator and contact with the brake pedal for the pedal manipulations.

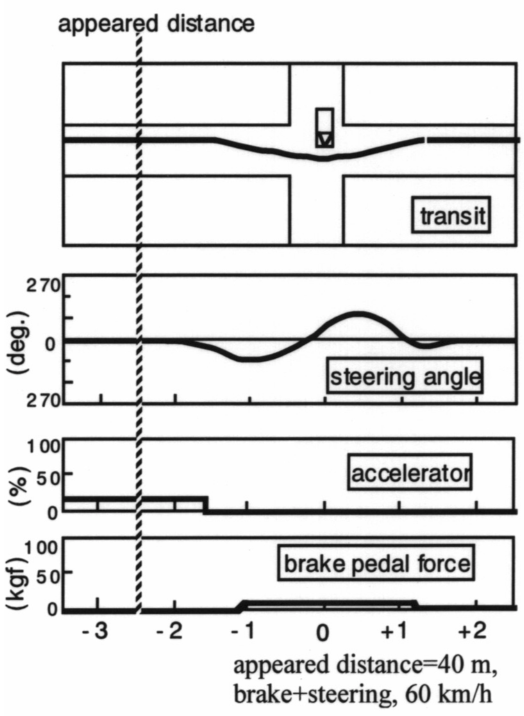

Figure 3 Typical Avoidance Behavior.

Figure 4 shows the mean values of the reaction times under the 60 km/h velocity conditions. Regardless of the difference in driver age groups, the reaction times tended to decrease as we decreased the appearance distances in every latency measure for steering and pedal manipulations. These results indicate that the drivers were likely to handle highly urgent situations by starting their avoidance behavior as early as possible when the obstacle vehicle could not be detected until immediately before the intersection. However, the shortest possible reaction times that the older drivers could realize were prolonged. For example, the shortest mean value of steering latency was 0.42 seconds for the older group, which was 0.1 seconds slower than the 0.32 seconds of the younger group.

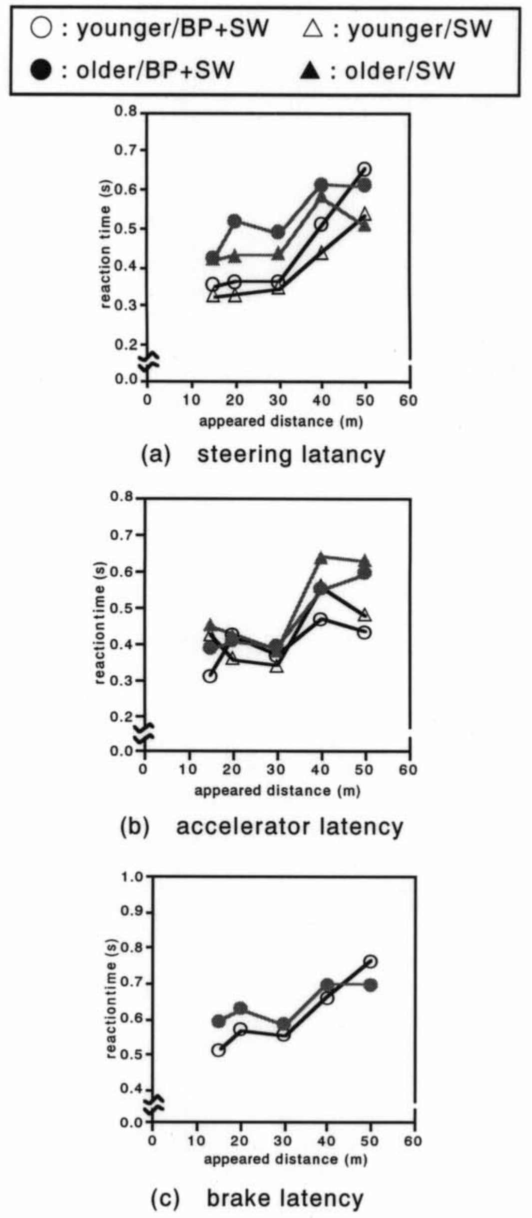

Figure 4 Reaction Times.

In contrast, the mean values of the steering angles and steering angular velocities tended to increase according to decreases in the appearance distances, as shown in Figure 5. This indicates that situational urgency forced the drivers to make faster and greater steering manipulations in this experimental situation. However, as in the above-mentioned latency measures, the capabilities of older drivers were relatively more restricted than those of the younger drivers in terms of steering avoidance. The mean steering angle at the first peak was around 100 degrees and the mean steering velocity to the first peak was limited to around 250 degrees/second for the older group. These performances were only half those of the younger group. The same tendencies were confirmed in the measures of the second peak.

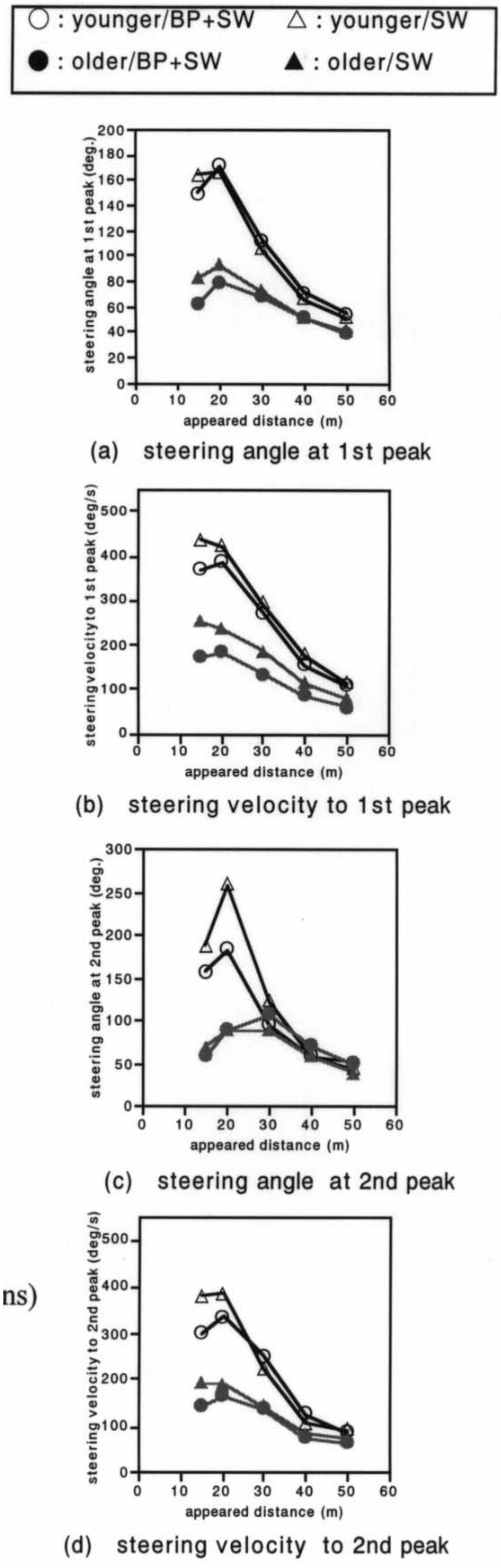

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Figure 5 Steering Maneuvers.

Though all drivers will exhibit relatively better performances in dealing with a situation if they are given more time to react, the emergent avoidance behavior that older drivers can realize in an urgent situation is more restricted than that of younger drivers in terms of reaction times and steering maneuvers.

Successful Avoidance

In this experiment, the time margin was defined as the value of the set appearance distance divided by vehicle velocity, and the relationship between the time margin and proportion of successful avoidances was examined. There was little effect of the differences in evasive actions and velocity factors on the relation between time margins and avoidance results, as shown in Figure 6. All drivers in the younger group failed the avoidance when the time margins were 1.2 seconds or shorter, and all succeeded if the time margins were 2.4 seconds or longer. In contrast, the border time margins between failed and successful avoidance by the older group ranged from 0.35 to 2.7 seconds. These results indicate that older drivers need a time margin 0.15 to 0.3 seconds longer than younger drivers to ensure successful avoidance in an emergent situation.

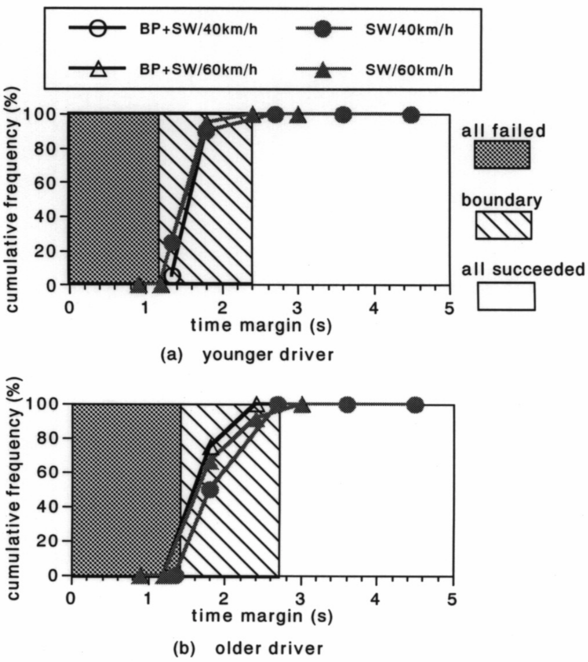

Figure 6 Successful Avoidance with respect to time margin.

Figure 7 outlines the failed avoidance of each group. More than 90% of the failures by the older group were accompanied by collisions with the obstacle vehicles, while relatively few deviations from the road (i.e., collisions with buildings) were observed. The failed avoidances suggest that insufficient steering angles and the steering angular velocities of older drivers, described in the above section, can bring about collisions with obstacle vehicles.

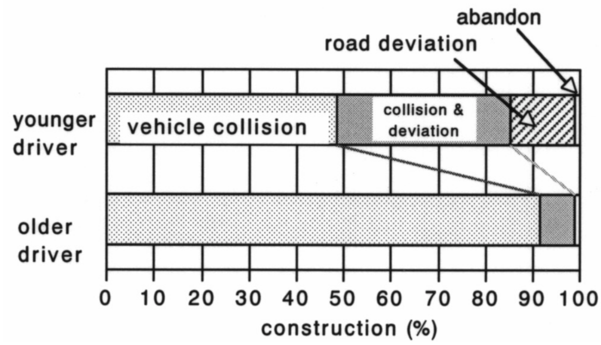

Figure 7 Constitution of Failed Avoidance.

Correspondences with Psychophysiological Traits

The critical time margin was defined as the individual value for each driver that distinguishes between failed and successful avoidance. We analyzed the relationship between the critical time margin and the psychophysiological traits. The critical time margin was calculated as the mean value of the time margins obtained in four conditions that combined evasive actions and velocity factors for each driver.

Figure 8 shows the distribution of critical time margins as a function of driver age. A portion of the drivers in their 50s needed a relatively longer time margin than younger drivers, and some drivers over 65 years could not succeed at avoidance if the time margin was shorter than 2.0 seconds. One notable point is the large individual differences across older drivers, evidenced by the fact that some older drivers could avoid the collision with a short time margin, as could the younger drivers, while remarkable deterioration was observed in other older drivers.

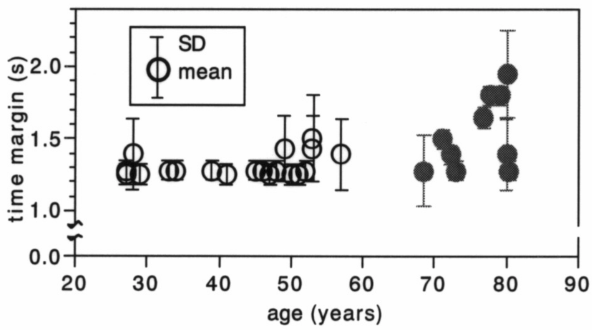

Figure 8 Distribution of Critical Time Margins as a Function of Driver's Age.

These individual differences in the avoidance performances of older drivers can be related to their psychophysiological traits. In a stepwise multiple regression analysis for the older group, conducted with the critical time margin as the dependent variable and the psychophysiological traits and driver age as independent variables, three traits were obtained that significantly contributed to the critical time margin with a multiple correlation coefficient R=0.672. Table 1 gives the coefficients of the significant traits, and Figure 9 shows the distribution of the measured critical time margins and estimations based on the obtained multiple regression. An examination of the coefficients of standard partial regressions suggests that avoidance capabilities are deteriorated if the older driver exhibits the following traits: advanced age, poor performance in multiple tasks, and a non stable-positive personality. The visual acuity and field of view of older drivers did not directly relate to the avoidance capability in this examination.

Table 1 Contributions of Psychophysiological Traits to Avoidance Capabilities of Older Drivers.

independent variables	coefficient for 3 variables	
	standard partial regression	partial regression
age	0.417	0.025
multiple task performance	0.157	0.035
personal trait	-0.342	-0.032
constant	-	-0.211
R	0.672	

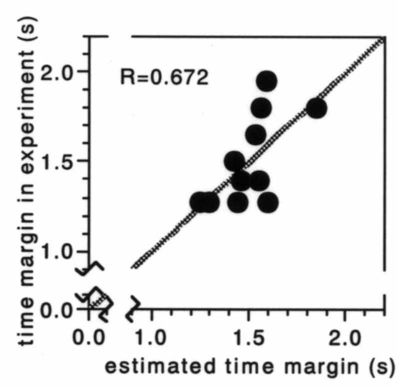

Figure 9 Correlation Between Estimated and Measured Critical Time Margins for Older Drivers.

Effectiveness of Advanced Warning

Figure 10 shows the cumulative frequencies of successful avoidance as a function of the time margin in a comparison of driving tests with and without advanced warning. All the younger and older drivers were successful in avoidance with a shorter time margin, less than 2.4 seconds, if the warning was presented from 50 m before the intersection, while some drivers failed the avoidance when the warning was not presented in advance.

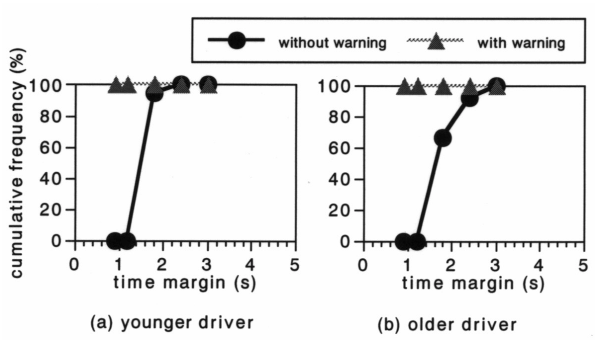

Figure 10 Effect of Advanced Warning on Avoidance Results.

Additionally, as illustrated in Figure 11, moderate steering maneuvers could be used to complete the avoidance when the warnings were presented. These results indicate the effectiveness of advanced warning in improving and compensating for the avoidance capabilities of older drivers as well as younger drivers.

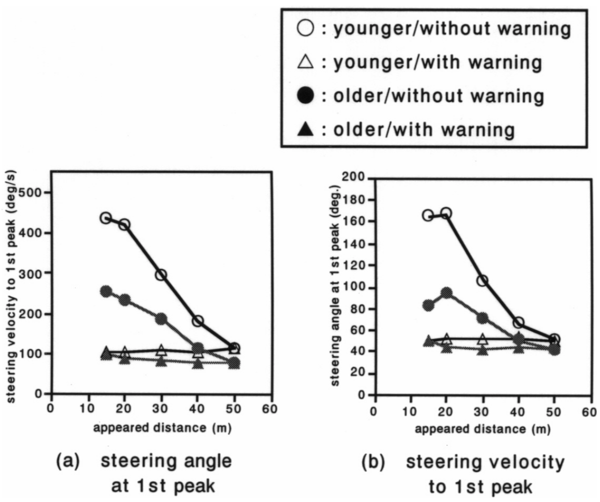

Figure 11 Effect of Advanced Warning on Steering Maneuvers.

CONCLUSIONS

The avoidance behavior of drivers over 65 years of age was measured in a simulated emergent traffic situation where an obstacle vehicle drives into blind intersections to clarify the avoidance capabilities of older drivers. The following properties were observed in a comparison of avoidance behavior between older and younger drivers:

(1) All drivers tended to realize their maximum performance to avoid collisions if they were close to the site of the dangerous event and the collision was anticipated. However, the abilities of older drivers are relatively more restricted than those of younger drivers in terms of reaction times, steering angles, and steering angular velocities.

(2) The time margins necessary to ensure successful avoidance by older drivers ranged from 1.35 to 2.7 seconds. This range is longer than the necessary time margins for younger drivers. Most failed avoidances by older drivers were collisions with obstacle vehicles, which can be attributed to insufficient steering maneuvers by older drivers.

(3) Individual differences in the time margins necessary to complete avoidance increase as the driver's age advances. The capability to perform multiple tasks and personality traits can be related to individual differences in emergent avoidance by older drivers.

(4) Advanced warnings are effective for older drivers and remarkably improve their avoidance performances.

Relatively low-speed driving behavior in urban intersections was examined in this research based on statistics of road vehicle accidents involving older drivers. However, the avoidance behavior of older drivers demonstrated in this study can be commonly observed in any situation where emergent reactions by a driver are required; the reaction times for older drivers are prolonged and the steering angle and steering velocity decline. As a result of this functional deterioration, older drivers require relatively longer time margins to complete collision avoidance than do younger drivers.

Safety education activities for advanced-age drivers are important current safety measures. They facilitate their awareness of their avoidance capability deterioration and compel them to drive carefully by clearly demonstrating their increased risk from their inability to avoid collisions once emergent situations occur. Furthermore, the activities of safety education using devices for driving aptitude tests are expected to be effective in improving the persuasiveness of safety education, based on experimental results that suggest a correlation between some psychophysiological measures and older drivers' avoidance performances.

Advanced warning systems, which are in research and development for the Intelligent Transport Systems (ITS), are also expected to be effective means to compensate for the deterioration of older drivers' performance. However, while the effectiveness of warning was confirmed in this study by no false alarms or missed warning conditions, in future examinations it will beis important to clarify the appropriate presentation timing depending on the type of warning and to ensure the reliability of warnings.

ACKNOWLEDGMENT

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